

54/09

RFB

Wind Tunnel Test Technique and Instrumentation Development at LaRC

By

Lawrence E. Putnam

Presented to

HSR Configuration Workshop

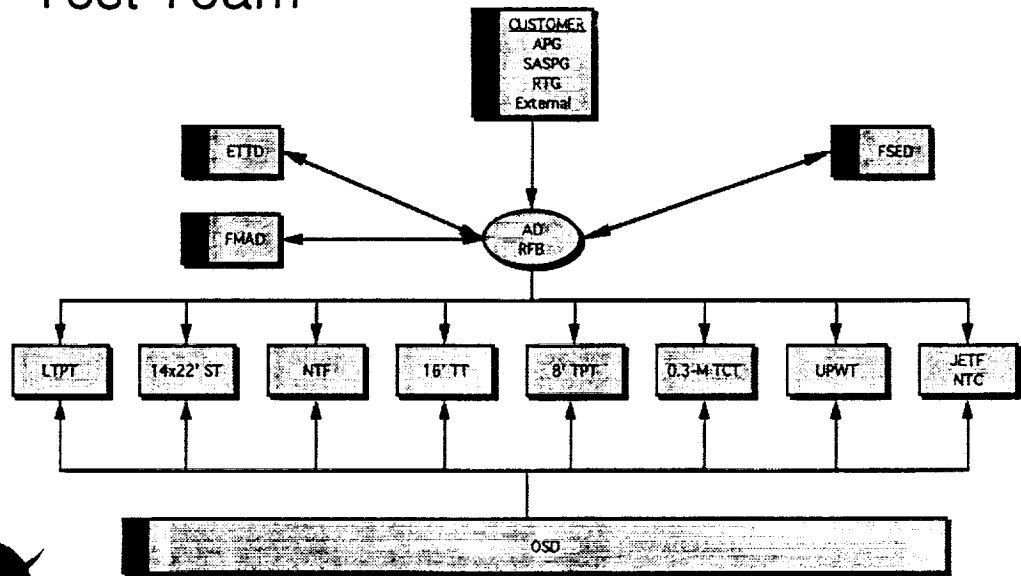
Feb. 28, 1996



Langley Research Center

RFB

Multi-Organizational Wind Tunnel Test Team



Langley Research Center

RFB

Areas of Test Technique Development



Langley Research Center

RFB

Test Technique Development Objectives

- Improved Basic Instrument Set
 - Provide capability to measure angle of attack to $\pm 0.01^\circ$ in a dynamic environment in ≤ 1 second.
 - Provide strain gage balances that are not effected by or that can be corrected for temperature gradient effects.
 - Provide balances that have significantly reduced uncertainty levels.
- Point Surface Flow Property Determination
 - Provide pressure measurement systems that minimize impact on tunnel productivity.
 - Reduce impact of electrical leads and pressure tubing that bridge the strain gage balance to zero.
 - Provide capability for measuring boundary layer characteristics.
 - Provide capability for measurement of unsteady flow characteristics.



Langley Research Center

RFB

Test Technique Development Objectives

- Global Model Position and Deformation
 - Develop optical methods for determining angle of attack with uncertainties of better than $\pm 0.01^\circ$.
 - Provide capability to measure model deformation under load in RFB wind tunnels.
 - Wing twist and deflection
 - High lift gap size
- Global Surface Flow Property Determination
 - Provide capability to determine boundary layer transition location at temperatures from 150 F to -250 F.
 - Provide user friendly pressure sensitive paint systems for RFB wind tunnels (in particular, UPWT, 16' TT, and the NTF in air).



Langley Research Center

RFB

Test Technique Development Objectives

- Global Off-Body Flow Property Determination
 - Provide non-intrusive capability to measure off body flow characteristics.
- Qualitative Flow Visualization
 - Provide non-intrusive surface flow visualization methods.
 - Provide non-intrusive off-body flow visualization methods.
- Semispan Testing Capability
 - Provide a semispan testing capability for NTF.
- Wall Corrections
 - Provide capability for routinely correcting data for wind tunnel wall effects.



Langley Research Center

RFB

Test Technique Development Objectives

- Data Uncertainty Assessment
 - Provide routine assessment of data uncertainty including bias and precision computation as part of data reduction.
 - Develop historical data base for uncertainty of all instruments.
 - Develop instrument calibration procedures that required uncertainty data.



Langley Research Center

RFB

FY 1996 Projects

- Improved Basic Instrument Set
 - Inertial Model Attitude Measurement System
 - Balance Thermal Response Improvement
 - Balance Modeling, Experimental Design and Uncertainty Improvement
- Global Model Position and Deformation
 - Assessment of OptoTrack Optical Model Attitude Measurement System
 - Development of single camera system for angle of attack and model twist determination.
 - Development of reflective plastic targets.
 - Development of laser scanning method for angle of attack determination
 - Development of laser scanning line targets.
 - Development of Moiré Interferometry method for model deformation determination.



Langley Research Center

RFB

FY 1996 Projects

- Point Surface Flow Property Determination
 - Development of a cryogenic ESP system for NTF.
 - Development of Bragg gratings for Shear Stress Measurement.
- Global Surface Flow Property Determination
 - Development of boundary layer transition location detection method for NTF.
 - Infrared method
 - Temperature Sensitive Paint
 - Hot films
- Qualitative Flow Visualization
 - Development of flow visualization systems for LaRC wind tunnels



Langley Research Center

RFB

FY 1996 Projects

- Data Uncertainty Assessment
 - Development of methodology for and assessment of data uncertainties in RFB wind tunnels.
- Wall Correction Method Development
- Semispan Test Technique



Langley Research Center

RFB

Development of Optical Angle-of-Attack Measurement Systems

- Objective
 - To develop a system of measuring angle of attack using optical techniques.
 - System shall be capable of a measurement accuracy of better than $\pm 0.01^\circ$ in a dynamic environment with no impact on tunnel productivity.
- Approach
 - Assess competing approaches through lab calibrations and prototype testing in wind tunnels.
 - Single Camera System
 - Two Camera System
 - OptoTrack
 - Laser Scanning Method
 - Select "best" system for implementation base on uncertainty of measurements and cost of implementation
- FY 1995 Accomplishments
 - Completed White Paper on state of art.
 - Completed lab calibrations and proof of concept tests in NTF and 16' TDT.
 - Completed initial comparison of OptoTrack(Boeing owned) and single camera system in the 14x22 tunnel.
 - Initiated procurement of OptoTrack.
- FY 1996 Plans
 - Develop high contrast targets.
 - Continue assessment of single camera system in the NTF.
 - Evaluate OptoTrack system..
 - Conduct risk reduction experiments for laser scanning method.
 - Document capabilities and measurement uncertainty of each approach
- Future Plans
 - Select best method and implement.



Langley Research Center

RFB

Development of Wing Twist Measurement System

- Objective
 - To develop an optical system for measuring wing twist caused by aerodynamic loads.
- Approach
 - A single camera videogrammetric system using high contrast passive optical targets on the model wing will be used to measure wing twist.
 - The target will have minimum adverse effects on the boundary layer.
 - System will be automated and user-friendly.
- FY 1995 Accomplishments
 - Completed White Paper on model deformation.
 - Demonstrated capability of system during tests in the NTF and UPWT.
 - Initiated effort to improve targets.
- FY 1996 Plans
 - Develop high contrast targets.
 - Continue assessment of single camera system in the NTF and UPWT.
 - Improve data acquisition system.
 - Refine calibration procedures to be more competitive with normal tunnel operations.
 - Document capabilities and measurement uncertainty.
- Future Plans
 - Implement production systems in NTF and UPWT.



Langley Research Center

RFB

Development of Model Deformation Measurement Systems

- Objective
 - To develop a system of measuring deformation using optical techniques.
- Approach
 - Assess competing approaches through lab calibrations and prototype testing in wind tunnels.
 - Laser Scanning Method - Uses a low-power, programmable laser beam scanning system, a galvanometer-based oscillating mirror and small infrared laser diode to paint a series of successive, parallel spanwise or chordwise lines of light on model which is recorded using CCD cameras.
 - Moiré Interferometry - makes use of optical fibers and infrared laser diodes as the basis of compact speckle interferometer systems.
- Approach Continued
 - Select "best" system for further development based on uncertainty of measurements, risk, and cost of implementation
- FY 1996 Plans
 - Acquire necessary hardware for laboratory tests of systems.
 - Perform laboratory risk reduction tests to characterize system performance and to obtain estimates of system accuracy.
 - Decide on whether to continue to development.
- Future Plans
 - If either systems shows enough promise, continue development of a prototype system and evaluate in wind tunnel tests.



Langley Research Center

RFB

Development of Bragg Gratings as Shear Stress Monitors

- Objective
 - To develop a non-intrusive method for quantitative shear stress measurements.
- Approach
 - Investigate the effects of aerodynamic shear stress on Bragg reflected spectra on germanium-doped optical fibers adhered to a metal substrate.
 - Conduct initial proof of concept lab studies to under variable aerodynamic stresses.
 - Conduct prototype testing of Bragg gratings in the ETTD subsonic wind tunnel and then the 0.3-m TCT.
 - If successful implement in the NTF.
- FY 1995 Accomplishments
 - Demonstrated that Bragg gratings exhibit measurable response to the applied shear stress.
 - Temperature effects which accompany the shear effect can accounted for by simultaneous temperature measurements.
- FY 1996 Plans
 - Conduct initial tests of concept in an appropriate wind tunnel.
- Future Plans
 - If prototype tests are successful, offer as a standard skin friction measuring technique.



Langley Research Center

RFB

Development of Cryogenic ESP Transducers

- Objective
 - To develop a ESP transducer that provides measurements at cryogenic temperatures without any type of thermal controls, that reduces number of ancillary pressure tubes crossing the balance, reduces number of calibrations required and is smaller in size.
- Approach
 - Basic ESP module design will be modified to incorporate materials that are compatible with cryogenic environment, temperature of each sensor will be measured to allow compensation for changes in bias and sensitivity, new bonding techniques will be used, and more highly doped semiconductors will be used to reduce sensitivity to temperature changes.
- FY 1995 Accomplishments
 - First 16 channel prototype system completed.
 - Thermal expansion measurements completed.
- FY 1996 Plans
 - Complete fabrication of 2nd and 3rd 16 channel prototypes.
 - Complete lab calibration and testing of 3 prototypes in 0.3-m TCT.
 - Complete analysis and selection of best fabrication method.
- Future Plans
 - Fabricate, calibrate and test 32 channel module.
 - Assess uncertainties
 - Seek commercial supplier and transfer technology.



Langley Research Center

RFB

Boundary Layer Transition Location Detection

- Objective
 - To develop user-friendly, cost-effective, minimally-intrusive method(s) for determining globally the location of boundary layer transition on models at temperatures from -250F to 130F.
 - To select by the end of FY, or sooner, initial technique(s) to be offered for routine use in the NTF.
- Approach
 - Assess competing approaches through lab calibrations and prototype testing in wind tunnels.
 - Infrared technique
 - Temperature sensitive paint
 - Hot film (not global)
 - Other
 - Select "best" system for implementation base on risk, technology readiness, cost of implementation, and uncertainty of measurements.
- Accomplishments to Date
 - Demonstrated use of IR technique down to about -150F. Will require long wave length IR cameras for lower temperatures.
 - Use of hot films down to -250F.
 - Potential of TSP in cryogenic environment by Sullivan of Purdue.
 - Team formed to develop TSP technique.
 - High risk research plan developed to provide a prototype TSP system in NTF by end of FY.
- FY 1996 Plans
 - Continue development of IR technique and define implementation requirements for NTF.
 - Conduct lab and exploratory wind tunnel studies to develop TSP.
 - Complete prototype test of TSP system in NTF.
- Future Plans
 - Select best method and implement in NTF.



Langley Research Center

RFB

Boundary Layer Transition Location Detection

- NTF Barriers and Constraints
 - Prototype system must be operational in facility by end of FY 96
 - Physical space (NTF running out of tunnel penetration space)
 - Changes/modifications should take no longer than 2 days
 - Transition data taken concurrently with other test data
 - No oil, seeding, O2
 - Must function from -250F to 130F
 - Access holes cannot exceed 2" diameter
 - Must be able to use existing models



Langley Research Center

RFB

Boundary Layer Transition Location Detection

- Infrared Technical Barriers and Issues

- Does not work on metal models
- Requires an insulated coating
- Thickness of silicon dioxide needed for insulation
- Probably need for a composite model
- Current technology limited to -150°F
- Exotic imager required
- Liquid helium cooled detector (-250°F)
- Background thermal noise on tunnel wall
- Special window glass
- Test section lighting
- Special enclosure required for camera
- 5 minutes/per point required for data acquisition
- Photon limited
- Can NASA specialist recreate experiments conducted by contractor in 0.3-m TCT?



Langley Research Center

RFB

Boundary Layer Transition Location Detection

- Hot Film Technical Barriers and Constraints

- Thickness of application
- Not global
- Time to calibrate
- Availability of facility to deposit films on large models
- Wire across balance
- Trench required for wires in wing
- Survivability of gauges in tunnel
- Surface of films
- Has problem with long cable lengths (>100ft)
- Fabrication capability (deposited films) only available at LaRC
- Probably could be used to validate other techniques
- High cost - impact on other measurements



Langley Research Center

RFB

Boundary Layer Transition Location Detection

- TSP Development Underway
 - Development of cryogenic paint chemistry
 - Cooperative effort between LaRC, HSR, MDA-E, Purdue University, and University of Florida
 - Development of insulating coating
 - Paint surface finish determination and improvement
 - Assembly of data acquisition system (using existing hardware and software developed for PSP)
 - Planning for 0.3-m TCT technique development and proof of concept tests
 - Definition of system implementation requirements for NTF.



Langley Research Center

RFB

Boundary Layer Transition Location Detection

- TSP Technical Barriers and Issues
 - Thickness of applied layer
 - Quality of surface finish
 - May require an insulating layer on model
 - May require a temperature step in flow
 - Orifice protection during application
 - Lighting contrast
 - Viewing angle/model shape
 - Life of paint
 - Degradation of paint
 - Keeping paint on model
 - Safety



Langley Research Center

RFB

DATA QUALITY ASSURANCE *Toward National Standards*

Our New Environment:

We are driven by customer needs.

New Customer Needs:

*Unprecedented assessment, control and
reduction of **variation** in design and testing.*



Langley Research Center

RFB

DATA QUALITY ASSURANCE *Toward National Standards*

Our Response:

1. Apply methods of **statistical process control** to all operations affecting measurement quality.
2. Establish **pre-test planning** and negotiation based on simplified, easy-to-use, uncertainty analysis.
3. Develop **standardized processes** for continuous improvement and long-term stability.
4. Develop **national standards** for evaluation of data quality and corrections in comparable national facilities.



Langley Research Center

DATA QUALITY ASSURANCE

Toward National Standards

Results So Far:

1. All RFB staff have completed Coleman and Steele short course on uncertainty analysis and test planning.
2. Simplified uncertainty analyses have been completed for core facilities plus airfoil tunnels.
3. Pre-test planning has led to significant changes in instrumentation and/or test matrix to achieve customer needs.
4. We have received strong, favorable, customer response.
5. Uncertainty analysis and statistical process control methods are now used to assess all changes in operations and facilities which might affect data quality.



Langley Research Center

DATA QUALITY ASSURANCE

Toward National Standards

Summary:

The new methodology has enabled us to look at our operations with a powerful microscope.

Consequence:

We can now see significant new opportunities to enhance customer and staff satisfaction while reducing costs and increasing productivity.



Langley Research Center

RFB

Test Techniques Available or in Development for LaRC Facilities used by HSR

- NTF
 - Micro-tuft surface flow visualization
 - Wing twist measurement
 - Boundary layer transition location (in development)
- UPWT
 - Schlieren or Shadowgraph
 - Micro-tuft surface flow visualization
 - Wing twist measurement (Prototype system demonstrated. Production system being developed.)
 - PSP
 - Vapor Screen



Langley Research Center

RFB

Test Techniques Available or in Development for LaRC Facilities used by HSR

- 16' TT
 - Micro-tuft flow visualization
 - Surface oil flow
- 14'x 22' Subsonic Tunnel
 - Micro-tuft flow visualization
 - Surface oil flows
 - Flying smoke wand
 - 3-D Laser Velocimeter
 - Global Doppler Velocimeter (development underway)
 - OptoTrack AOA (in procurement)



Langley Research Center

Concluding Remarks

- LaRC has an aggressive test technique development program underway. This program has been developed using 3rd Generation R&D management techniques and is a closely coordinated program between suppliers and wind tunnel operators.
 - Wind tunnel customers' informal input relative to their needs has been an essential ingredient in developing the research portfolio.
- An attempt has been made to balance this portfolio to meet near term and long term test technique needs.
- Major efforts are underway to develop techniques for determining model wing twist and location of boundary layer transition in the NTF.
- The foundation of all new instrumentation developments, procurements, and upgrades will be based on uncertainty analysis.



Langley Research Center

